

Semantic Progressive Transmission for Deep Space Communications

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We present an integrated system for the intelligent progressive transmission of data for deep space communications. This work is motivated by the realization that much more information can be collected by imaging and remote sensing equipment than can be transmitted through downlink channels. The goal of this work was to extend the idea of progressive transmission by incorporating semantic value to the “importance” attributes of encoded data. In particular, we define a simple measure of *science return* based on information theoretic considerations as well as on the estimated *scientific value* of the transmitted data. The task of determining the relative scientific importance of segments of data is carried out by an *onboard science processing* module, designed according to guidelines provided by the remote user (the science community.) This module pre-processes the image and provides input to the progressive encoder in the form of a suitable “classification map”. By combining the semantic characterization produced by the science processing module with the content-blind data organization criteria of traditional progressive encoder, we obtain a new measure of the “importance” of each segment of data. Algorithms that best utilize the available resources can thus be designed and their performances in terms of science return assessed. Note that it is not necessary that classification maps be defined just on the spatial domain. For example, one may characterize multispectral imagery not only by the image segments corresponding to features of interest, but by the characterization of the multispectral features themselves (expressed in terms of the most relevant bands or perhaps by a suitable combination of bands).

Bit-plane ordering provides perhaps the simplest instance of progressive data encoding. To keep science value into account, we should modify the simple notion of “importance” by considering a combination of bit-plane index and classification value. The resulting “priority” values represent the overall importance of a bit of information. The data stream is then prioritized according to its significance in the image, and the most significant segments of data are transmitted first by means of a prioritized buffer management strategy. The goal of the combined encoding/buffer system is to maximize the value of data transmitted and minimize the value of data lost due to buffer overflow. We introduce a control strategy that maximizes the buffer’s usefulness by keeping it constantly full and overflowing. We show that this system allows to optimally exploit the limited onboard resources (downlink data rate, buffer size) and therefore to maximize the science return of a mission. To evaluate the performance of the onboard buffer manager in isolation from that of the onboard science processor, we define the *discriminatory power* of the onboard buffer manager in terms of its ability to process for transmission the same number of data segments that are deemed most important by either an “ideal onboard scientist” or an automated onboard science processing system.

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